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INVENTORY REDUCTION USING BUSINESS PROCESS REENGINEERING AND SIMULATION MODELING

by

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Inventory reduction is one of the most critical areas facing DoD in this era of diminishing resources and increasing global comittments. This thesis analyzes the concept of cycle time reduction as a significant method to reduce inventory levels. The order fulfillment process of a distribution center is analyzed using simulation modeling and business process reengineering (BPR) concepts. The two simulation models were designed and evaluated by measuring the cycle time of an order flowing through the distribution center. The results indicate that the cycle time of the order fulfillment process can be reduced by 90%, inventory levels reduced by 77% with a labor savings of $60,000. This was achieved by reengineering the order fulfillment process from a batch system to one that sends incoming orders directly to the warehouse for order selection. The implications for the DoD are critical to the goal of inventory reduction; by focusing on the reduction of cycle time, in-process inventories are also be reduced. The use of business process reengineering and simulation modeling offer powerful tools to aid the manager in reducing cycle time and inventory levels.

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INVENTORY REDUCTION USING BUSINESS PROCESS REENGINEERING AND SIMULATION MODELING

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Inventory reduction is one of the most critical areas facing DoD in this era of diminishing resources and increasing global comittments. This thesis analyzes the concept of cycle time reduction as a significant method to reduce inventory levels. The order fulfillment process of a distribution center is analyzed using simulation modeling and business process reengineering (BPR) concepts. The two simulation models were designed and evaluated by measuring the cycle time of an order flowing through the distribution center. The results indicate that the cycle time of the order fulfillment process can be reduced by 90%, inventory levels reduced by 77% with a labor savings of $60,000. This was achieved by reengineering the order fulfillment process from a batch system to one that sends incoming orders directly to the warehouse for order selection. The implications for the DoD are critical to the goal of inventory reduction; by focusing on the reduction of cycle time, in-process inventories are also be reduced. The use of business process reengineering and simulation modeling offer powerful tools to aid the manager in reducing cycle time and inventory levels.

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A. BACKGROUND

1. Overview

Since the end of the Cold War, the DoD has been under increasing pressure from its stakeholders, such as Congress, to reduce the size of its operations. One need only perform a cursory review of newspaper headlines for the last five years to see the pressure that the DoD is receiving from its many stakeholders. One area that the DoD has looked at closely is the streamlining and improving of its logistics operations, and more specifically, its secondary item inventory levels. A secondary inventory item is any item that is used to support the operating forces. Examples of secondary items include food, clothing , medical, and hardware supplies.

In 1989, secondary item inventory levels were valued at $92.5 billion; by 1993, DoD had managed to reduce that level to $77.5 billion. However, in spite of this $15 billion inventory reduction, the Government Accounting Office (GAO) believes DoD has yet to achieve effective and efficient inventory management (GAO, February 1995, p. 13). In recognition of these criticisms, the 1995 DoD Logistics Strategic Plan states a target inventory level of $52 billion (FY 93 constant dollars) by October 2001 in its secondary item inventory levels (Deputy Under Secretary of Defense (Logistics), 1995, pp. 20-21). This represents a 72% reduction from 1989 inventory levels. One way to significantly reduce inventory levels is by reducing cycle times.

The remainder of this chapter will look at the problem of inventory and cycle time reduction, DoD logistics goals, research questions that will be examined in this thesis, and the methodology that will be used to answer the research questions.

2. Cycle Time Reduction

The 1995 edition of DoD's Logistics Strategic Plan states:

> Time is the enemy of logistics. Each day of delayed response to the user represents millions of dollars in inventories waiting to be moved, repaired, delivered, stowed, and used. The best private sector practitioners of logistics have distinctly moved towards reducing cycle times (p. 13).

This thesis will examine reduction of cycle time as one of the methods that can be used to reduce inventory levels. It will be shown that long cycle times lead to increased levels of inventory because inventory is used to cover cycle time and protection against uncertainty. Cycle time is defined as "the elapsed time between the time a customer order, purchase order, or service request is placed and the time it is received by the customer." (Ballou, 1992, p. 85) Cycle time is often synonymous with logistics response time, order fulfillment cycle, and turnaround time. Lengthy cycle times both drive the need for increased inventory levels and undermine the customer confidence in the supply system. "Lengthy" in this sense is a relative term; if ten pads of paper and two boxes of pens are ordered through the supply system and it takes three weeks to receive them, then that is a long time when considering that the customer could have gone to the local office supply warehouse and purchased them the same day. By driving down lengthy cycle times, the amount of inventory necessary to support the customer can be lowered. These two goals, inventory and cycle time reduction, are inextricably woven together. If it can be shown how cycle time reduction can reduce inventory costs, achieving two of the DoD's logistics goals are feasible:

1. Reduce logistics response time.
2. Reduce inventory investment.

Therefore, this research will focus on reducing inventory levels by shortening the logistics response time. The research will examine how a decrease in the order fulfillment cycle of a product can reduce inventory levels. The concept of reengineering will be defined and used to examine and improve the order fulfillment process.

B. RESEARCH QUESTIONS

This research will attempt to answer the following questions and issues:

1. Identify the order fulfillment cycle from order entry through final shipment to the customer. Emphasis will be placed on graphically demonstrating areas for improvement.
2. What will be the effects of reengineering the process on inventory levels?
3. What costs and cost savings will be associated with the proposed process change?
4. What is the present value of these process changes over a five year period?

C. DISCUSSION

The 1995 Department of Defense Logistic Strategic Plan highlights the need for greater logistics performance and flexibility. Specifically, according to the plan, "better and faster information is critical to **shortening cycle times**, to reduce risk to the Department and its suppliers, to optimize expenditures, and to **cut investment in potentially obsolescent inventories."** (DoD, 1995, p. 2) Goal number one of the plan is to reduce logistics cycle times. The emphasis in attaining this goal should fall on process reengineering, including analytic processes such as modeling and benchmarking, to identify and adopt the most successful government and commercial practices, and to minimize costs across functions. Goal 3.A.1 of the plan, titled Inventory Reduction, tasks the Office of the Secretary of Defense (OSD) and its components to continue to reduce inventory levels of secondary items for those items no longer necessary for readiness support. The reduction will be measured as the value of the inventory at the end of the year and the quantity of storage necessary to hold that inventory.

In support of the above objectives, this research will be directed toward reducing cycle times in typical DoD distribution centers (DC). The DC under analysis is the General Services Administration's (GSA) Customer Support Center in Stockton, CA. Specifically, the order fulfillment cycle will be examined from the time an order is received to the time when it is shipped to the customer.

Using Little's Law (Little, 1961, pp. 383-387):

Inventory = Throughput Rate x Turnaround Time,

it will be shown that, by reducing the cycle time, the amount of inventory necessary to maintain a given level of readiness can be reduced.

D. METHODOLOGY

In order to accomplish the objectives and demonstrate the effects of reduced cycle times on inventory levels, data will be obtained by conducting interviews with on-site personnel to determine current process procedures, inventory costs, throughput rates, and turnaround times. Demand rates and process times will be gathered. The costs of any recommended capital improvement will be estimated by consulting industry references and practices.

Once the initial data has been collected, it will be scrubbed and any additional data requirements will be indentified. A simulation model will be developed using actual data to measure turnaround time and to count the number of unprocessed orders at the end of the work day. The simulated process will then be reengineered and the effects on cycle time will be measured. Once all the changes have been made and measured, analysis will be conducted to determine the effect of these changes on the inventory levels. Present value techniques will examine savings generated.

E. STRUCTURE OF THE THESIS

This study will be limited to examining a single representative site. The GSA customer support center consists of approximately 2,000 line items. The aggregate changes to the inventory levels will be analyzed. The simulation model developed uses actual data to analyze the underlying probability distribution for the number of orders received and the size of an individual order. In the absence of actual data, process times were estimated based on interviews with on-site personnel. An "as is" cycle time will be measured and then compared to a reengineered model. Analysis will then be conducted to show how this change will result in cost savings. A break-even analysis will be conducted to determine how long it will take to pay back any capital investments.

The thesis is divided into five chapters and is based on models developed using the site mentioned above. Chapter I has presented the problem, stated the objective of the thesis and the associated research questions, described the scope of the research effort, and previewed the research methodology. Chapter II discusses background material on warehousing and distribution, reengineering, DoD inventory and simulation modeling.

Chapter III develops and analyzes the simulation model for the GSA site and includes both "as is" and reengineered processes. The effects of the reengineered process will be analyzed with a focus on cycle time reduction. Chapter IV presents a a comparative analysis of the two models and the implications for reducing inventory levels. Chapter V presents a summary of the thesis efforts, conclusions from the research, and recommendations for further study.

II. BACKGROUND

A. INTRODUCTION

In this chapter, background material will be reviewed to provide an understanding of warehousing and distribution, inventory in a distribution center, the relationship between cycle time and inventory, reengineering, DoD inventory and simulation modeling. Each area will be discussed in turn.

B. WAREHOUSING, DISTRIBUTION AND INVENTORY

1. Difference Between a Distribution Center and a Warehouse

The primary difference between a distribution center and a warehouse relates to the differences in the reasons for their existence. A distribution center's primary purpose is to move product out the door to some customer. A warehouse, on the other hand, exists primarily to store product, and, secondarily, to ship that product to a customer. A distribution center emphasizes product flow while a warehouse emphasizes storage (Tomkins and Smith, 1988, p.29). This thesis is concerned primarily with distribution centers and the goods or inventory that flow through it. If a distribution center is focused on product movement and, more specifically, on product movement to a customer, then it is critically important to get that product from the receiving docks to the shipping door, (i.e., cycle time) as quickly as possible. There are many companies that have done exactly this with their distribution centers. They have refined the movement of product to the customer to an exact science. Attention will now be turned to looking at what a world class distribution center would look like.

2. World-Class Distribution Centers

The 1995 DoD Logistics Strategic Plan states, "achieving world-class capabilities, while reducing the cost of DoD's logistics system, is the principal challenge of this plan." (DoD, 1995, p. 9) It also states, that in order to attain its vision, it will make selective investments in technology and benchmark (i.e., compare itself to) other successful commercial sources and practices (DoD, 1995, p. 5). If this is to be done, distribution centers that exemplify world-class status must studied and bench-marked . A world-class distribution center is one that can compete successfully anywhere in the world and they obtain excellence by meeting customer requirements through continuous improvement (Heizer and Render, 1996, p. 44). Reduction goals of 90% of pipeline inventories and lead time are now relatively common, especially among the most dynamic industry leaders. Some examples of companies that have achieved significant reductions in their inventories and cycle times include:

1. Altos Hornos De Vizcaya, S.A.: manufacturer of steel strips and coils, achieved customer service lead time reductions in made-to-order products of 45%, and standard strip of 75%. Inventory investment reduction of 30%.

2. Metro Drug Corporation: distribution division. Pharmaceuticals and consumer products. Customer service lead time reduction, 66%,

3. IBM: Martinez plant. Printers and tape drives. Reduced material receipt and issue lead time by 75%.

4. Epson Australia Limited: Personal computer and printers. Customer service lead time reduction, 66%; Inventory investment reduction, 66%

Recent laudable achievements fall in the range of the following improvement percentages; 50% faster customer service lead times, 50% reduction of inventory investment in the logistics and production pipelines (Harmon, 1993, p. 1). The above two goals are exactly the aim in this thesis.

A list of traits, compiled from Heizer and Render (1996) and Harmon (1993), that a world-class distribution center would exhibit might look something like the following:

1. An obsession with the customer. The entire distribution center should be driven by customer demands.

2. A focus on quality. In a distribution center, that means fast delivery and error free shipments.

3. Use of information technology to attain a competitive advantage. Technology is not used for the sake of technology, but to attain a competitive advantage, such as faster delivery or error free shipments.

4. Pay systems are linked to performance. The output of the system, as defined by all involved in the process, is inextricably linked to how much workers get paid.

5. Small is beautiful! Every inch of distribution space is used.

6. Ceaseless movement of inventory through the system. Inventory is received just-in-time and flows immediately through the facility to meet customer demand.

7. Only those processes that add value to the customer become part of the order fulfillment cycle.

8. Employees are well-trained in all aspects of the business.

9. Information is shared and made visible to employees, customers and suppliers.

10. Work processes are measured, posted, shared with everyone, and constantly improved.

The above list can provide a good road-map in the drive for decreased cycle times. Cycle time relates directly to customer service, speed of delivery, ceaseless movement of product and measurement of work processes. The other items on the above list; space utilization, training, focus of value added activities, and information technology, can be seen as activities that will improve the organization's goal of reducing cycle time in a distribution center. What purpose does inventory serve in a distribution center? Do we need any inventory? These are questions to which our attention will now be turned.

3. Inventory in a Distribution Center

In the definition of a distribution center, it was stated that it was primarily concerned with product flow. Theoretically, the inventory in a distribution center should flow in one door and instantaneously flow out the shipping door to meet customer demand. Anything that does not add value to the goal of getting the product to the customer is waste. Inventory serves several purposes, one is to meet customer demand and another is protection against uncertainty. The uncertainty is protected by safety stock. If something unexpected happens, safety stock can be used to satisfy this unexpected requirement. It is like an insurance policy, protection against some unknown future event. That future event in this case is customer demand. The better customer demand can be forecasted , the less uncertainty in demand, the faster inventory can get out the door, and finally, the less inventory that will be on-hand. The focus of a distribution center, therefore, is to ensure that inventory is on hand to meet customer demand and that product's cycle time or flow through the warehouse is as fast as the system will allow.

4. Cycle Time as it Relates to Product Movement

In distribution centers, product arrives at different times, is stored in the system, and is then shipped out to customers as demanded. One way to estimate product movement is by using Little's Law (Little, 1961), one of the most widely used equations in queuing theory. The beauty of this formula is that it works regardless of the underlying probability distribution of the process. Any system that transforms input to output over time, and possesses steady state performance measures corresponding to mean length of system (L), mean throughput rate (R) and mean waiting time in system (W), will obey this law (Ravendran, Phillips, Solberg, 1987, p. 314-315). For example, in queuing theory, it relates the average number of customers in a system (L), mean arrival rate (R), and average system time (W) (Graves, Kan, and Zipkin, 1993, pp. 207-209). Stated as:

Average Number of Customers in a System (L) =
Mean Arrival Rate (R) x Average System Time (W)

In the case of a distribution center we can relate the average value of inventory (L) to the throughput rate of the process (R) and the turnaround time of an order (W). Reformulated, Little's Law now states that:

Average Inventory Level in System (L) =
Throughput Rate (R) x Turnaround Time(W)

Little's Law is now interpreted to state that the in-process inventory for the distribution center equals the production rate of the distribution center multiplied by the average flowtime of orders flowing through the distribution center. From the above formulation, it becomes clear that if the amount of time it takes to process an order is reduced (cycle time), the average value of the inventory in the system can be reduced. In recent years, an increased emphasis has been placed on cycle time reduction because it gets the product to the customer faster due to increased turnover rates, thus reducing the amount of inventory the organization has to carry . This drive for cycle time reduction has indeed become a characteristic of world-class distribution centers.

C. INVENTORY MANAGEMENT IN THE DEPARTMENT OF DEFENSE

1. Background And Current Status

In 1989, DoD's military forces included roughly 2.1 million active duty soldiers, sailors, marines and airmen; over 2,800 attack and fighter aircraft; about 570 ships; and 18 active Army divisions. In support of these forces, DoD had inventories of spare and repair parts, clothing, medical supplies, and other support items valued at $92.5 billion (GAO, February 1995, p. 9). By 1993, active duty military personnel had decreased to about 1.7 million, active attack and fighter aircraft to about 2,100, ships to 435, and active Army divisions to 14. With the end of the Cold War and the collapse of the Soviet Union, DoD was forced to significantly reduce all aspects of its operations. Between 1989 and 1993 the value of DoD's secondary item inventory decreased by $15 billion, to about $77.5 billion (GAO, February 1995, p. 9). The DoD maintains about 600 million cubic feet of warehouse space, two-thirds of which is occupied by secondary items. According to the Defense Logistics Agency (DLA), these secondary items occupy storage space in 1,400 warehouses and 27 distribution depots.

In 1995, the GAO had this to say about what it considered DoD's excessive inventory levels:

> The problem resulted from DoD's culture that believed it was better to overbuy items than to manage with just the amount of stock needed. The culture prevented DoD from using cost effective inventory management and control techniques and modern commercial inventory management practices that would allow lower inventory levels. (GAO, February 1995, p. 6)

They go on to state that, "although we have seen pockets of improvement, DoD has made little overall progress in implementing the long-range actions necessary to effectively and economically manage its inventory."

2. The Future

It is clear from the above that current inventory management practices cannot continue. The question that needs an answer is: how does the DoD reduce the levels of inventory? For the answer to these questions, let's take a look at the 1995 DoD Logistics Strategic Plan. In the Objectives and Strategies portion of the plan, goal 3A reads "implement the most successful private sector business practices." One of those successful business practices is inventory reduction. The target inventory level is a reduction to $52 billion by 2001. Of course, any grand plan such as this is lacking in specifics on how to achieve this reduction. The DoD Plan talks throughout of reducing cycle times to improve customer service. The reduction of cycle time in a distribution center process offers a significant method to reduce the amount of inventory that DoD holds. The concept of reengineering offers the DoD a way to analyze and evaluate a business process, such as the order/fulfillment cycle in a distribution center. By reengineering the order/fulfillment cycle, a significant reduction in cycle times may be achieved.

D. REENGINEERING A BUSINESS PROCESS

1. What Is Reengineering?

Reengineering is nothing new. It is not a new concept, a new business process, or a new management tool. Through the years, it has been called many names; process improvement, restructuring, reorganizing. Reengineering is defined as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed" (Hammer and Champy, 1993, p. 32). Business processes can be thought of as a set of tasks typically crossing organizational boundaries which deliver something of value to an internal or external customer (Bhaskar and others, 1994, p. 1207). These business processes were most likely never engineered. They have not been engineered with any broad business goals in mind Rather they have been cobbled together over the years in response to isolated events or crises. As a result of this reactionary approach to business process design, today's business processes contain an enormous amount of waste and non-value added content. Business process reengineering (BPR) attempts to fundamentally re-design or reengineer a company's business processes. This thesis will use the concept of reengineering to mean the systematic evaluation and refinement of a business process to attain reductions in inventory levels and costs.

2. Successful Reengineering

It is important to think of reengineering not as a project, but as a way of life, a continual and never-ending process. When the organization thinks it has finished reengineering a process, it must start again and make the process even better. The entire organization must be looked at to see what else can be reengineered. There are some key points to remember when attempting to reengineer a business process.

The following points, taken from Hammer and Champy's 1993 book "Reengineering the Corporation: A Manifesto for Business Revolution." (Hammer and Champy,1993, pp. 201-212), spell out what a successful reengineering effort will take.

1. Do not fix a process, change it.
2. Focus on business processes.
3. Everything associated with the process must be refashioned.
4. Do not ignore peoples values and beliefs.
5. Do not settle for minor results, aim for dramatic improvement.
6. This is a long-term effort, do not quit too early.
7. Do not place prior constraints on the definition of the problem or the scope of the reengineering effort.
8. Do not allow existing corporate cultures and management attitudes prevent reengineering from getting started.
9. Reengineering must happen from the top down.

10. Assign someone who understands reengineering to lead the effort.

11. Do not skimp on resources devoted to the reengineering effort.

12. Put reengineering at the top of the organizations agenda.

13. Focus on a few reengineering projects at a time.

14. Ensure the head of the organization is going to be around for a while.

15. Do not allow reengineering to become the program of the month. Ensure it is distinguished from other business improvement programs.

16. Do not pull back when people resist reengineering changes.

From the above list, it can be seen that BPR is not for the faint of heart. It will involve sacrificing many sacred cows to the god of value-added activities. Only those activities that serve the purpose of the business will be allowed to remain. All other activities can either be eliminated or contracted out to other organizations. In the case of reduced cycle time, only those activities that contribute to the goal of getting the product to the customer will be considered to be value added. Any extraneous activities will be eliminated in the reengineered simulation model. Attention is now turned to how simulation modeling can be used to reengineer a business process.

E. SIMULATION MODELING AS A TOOL TO UNDERSTAND AND REENGINEER A BUSINESS PROCESS

1. What Is Simulation Modeling?

Simulation can be defined as the process of designing a model of a real system and conducting experiments with the model to gain an understanding of the behavior of the system. These experiments can also aid in the evaluation of various proposed strategies for the operation of the system (Pegden, Shannon and Sadowski, 1995, p. 3). According to Tomkins and Smith (1988, p. 162),

> Through the use of modern systems simulation tools, technologies, and methodologies, the systems analyst can accurately predict the behavior and operational characteristics of complex systems before they are actually installed.

As engineers build simulations of a ship's flow through the water and aircraft pilots train on simulators that recreate the physical world in which they fly, complex manufacturing systems can be also be simulated. All of these simulations use a model to represent the behavior of a system that may or may not exist and that is larger, costlier and more complex than the model (Seila, 1995, p. 7). The key idea is that, "the simulation is an alternative realization that approximates the system and, in all cases, the purpose of the simulation is to analyze and understand the system's behavior under various alternative actions or decisions." (Seila, 1995, p. 7) It is critical to understand that the use of simulation is not a panacea to fix a bad process. It is simply a tool that can help the manager understand a process and to evaluate "what if" questions.

2. Why Use Simulation to Reengineer a Business Process in the DoD?

In the private sector, the increasing competitive pressures to speed the delivery of products to market, minimize product development times, reduce inventory levels, fulfill demand, and service customers has led to a fundamental re-thinking of the way business is done. This is no less true in the DoD, the only difference being the focus on reducing costs vice maximizing profits. The DoD still must service customers, reduce inventory levels, develop weapons systems, fulfill demand and deliver spare parts to the fleet. This must all be done under reduced funding and manning levels. As a result, the DoD has also had to fundamentally re-think and re-engineer the way it is doing business. In the past, spreadsheets, flowcharts and management intuition have been used to re-engineer a business process. The problem is that these techniques cannot fully answer "how," "when," or "where" questions. Business processes are far too complex and dynamic to be understood by flowcharting and spreadsheet techniques (Tumay, 1995, p. 55). Therefore, business process simulation is a better tool in the decision making process due to its ability to handle more complex scenarios.

The experience of designing a simulation model of the process forces the analyst to delve into details of the systems so that one first understands the process. The experience of designing the model may be more valuable than the actual simulation as it may suggest changes that may not have been previously considered. Is simulation modeling better than the typical analytic planning tools? Again, according to Tomkins and Smith (1988, p. 164):

> By and large, analytical planning tools used in industry utilize only point estimates or expected value statistics. Computer simulation models address a stochastic world that is described by probabilistic measures: empirical density functions, probability density functions, or process dependent state equations. The long-run acceptability of a system is more dependent upon system surges or variabilities than any other factor. Simulation allows an analyst to both incorporate these factors into the model and study the behavior of the system under their influences.

Reengineering a business process involves the interaction of people, processes, machinery and technology over time. These interactions yield an infinite number of possible outcomes and scenarios that are far too complex to understand and evaluate without the use of a simulation model.

3. Characteristics of a Successful Simulation Project.

There are four main phases to designing a successful simulation project. They are 1) problem definition, 2) model building and testing, 3) experimentation, and 4) project completion. The problem definition phase involves five stages. They are 1) problem identification and setting the objectives, 2) definition of experimental factors and reports,

3) determining scope and level of model, 4) collection and analysis of data, and 5) project specification provisions. The three stages of model building and testing are, 1) model structure, 2) building the model; coding, documenting and verifying, and 3) model validation. The experimentation phase involves the determination of warm-up periods, run lengths, replications, analysis of results and drawing conclusions. In the project completion phase, results must be communicated, documentation must be completed, and the project must be reviewed. (Robinson and Bhatia, 1995, p. 64)

4. How Will Simulation Be Used in This Thesis?

The simulation model for this research examines cycle time process, i.e., the process from the time an order is received until the time it is shipped. The GSA Distribution Center being modeled has approximately 2,000 line items of inventory. One year of demand data was analyzed to determine the demand rate. The model will simulate 30 days of system processing. The Arena simulation software package will be used to demonstrate and measure the impact of reengineering the cycle time system. The measure of effectiveness that will be used is, cycle time, i.e., the average time an order spends in the system. The average time an order spends in the system, or more simply, cycle time, is defined as the elapsed time between the time a customer order is placed and the time it is transferred to the shipping agent. The goal is to show that if cycle times can be reduced, the amount of inventory required to keep that inventory can be reduced.

III. DEVELOPMENT AND ANALYSIS OF GSA'S CUSTOMER SUPPORT CENTER

A. WHAT IS THE GENERAL SERVICES ADMINISTRATION (GSA)?

1. The GSA Organization

GSA is the United States Government's largest buyer of goods and services for government entities all over the world. It consists of a headquarters in Washington D.C. and ten (10) regions:

1. National Capital Region - Washington, DC.
2. New England Region - Boston, MA.
3. Northeast and Caribbean Region - New York, NY.
4. Mid-Atlantic Region - Philadelphia, PA.
5. Southeast Sunbelt Region - Atlanta, GA.
6. Great Lakes Region - Chicago, IL.
7. The Heartland Region - Fort Worth, TX.
8. Rocky Mountain Region - Denver, CO.
9. Pacific Rim Region - San Francisco, CA.
10. Northwest/Arctic Region - Auburn, WA.

This research is concentrating on the Pacific Rim region (9) and its distribution center located in Stockton, CA.

2. The Pacific Rim Region

GSA's Distribution Center in Stockton, CA. serves the Pacific Rim area and covers the states of California, Arizona, Nevada and Hawaii as well as Guam and the Pacific Rim

Territory Islands. Within this distribution center, GSA has carved out a limited number of items that it offers to customers for a premium price in return for faster delivery times. The items held in this area are located at the Customer Support Center (CSC). The CSC promises delivery within three business days versus the standard three to four week delivery time, and they generally get a 25% price premium for this service.

3. The Federal Supply Service

The GSA Federal Supply Service (FSS) provides billions of dollars worth of goods and services to government entities throughout the world. To streamline its operations, the FSS has organized its supply support functions into commodity centers. Commodities and services are assigned to specific GSA commodity centers for procurement and related supply functions including inventory management, engineering, and requisition processing. The commodity centers include ADP, General Products, Furniture, Office Supplies and Paper Products, Office and Scientific Equipment, Paints and Chemicals, Services, and Tools and Appliances. The CSC primarily carries general products, office supplies and paper products, office and scientific equipment, and some smaller tools and appliances. It is these types of items that flow through GSA's CSC in Stockton, CA. These will be the items of inventory that the simulation model will track and measure with respect to cycle time. These are the items that customers order when they call into CSC's order desk. A description of the order process will be described in the next section.

B. GSA'S CUSTOMER SUPPORT CENTER ORDER FULFILLMENT PROCESS

1. The Order Fulfillment Process

GSA started the CSC in response to customer demands for faster service. It realized that an increasing quantity of its demand for products was for small dollar value items that could be selected and packaged rapidly and without special handling. The CSC is a separate section of GSA's distribution operation and has order clerks and warehouse people dedicated to its operation. They have also carved out separate warehouse space to stock CSC items. The CSC operates Monday through Friday from 0700 to 1530. The United Parcel Service (UPS) and the United States Postal Service (USPS) are both located in the CSC warehouse to facilitate product shipment.

The CSC receives approximately 2,300 requests per day for individual line items. This translates into approximately 380 orders per day. Orders arrive, on average, every 1.27 minutes. Phone calls are handled by a bank of 7-10 order clerks. Once the order is taken, it is sent to the print buffer. Data analyzed from June 1995 to May 1996 indicate that the average size of an order is approximately six line items. Every two hours, orders are printed and walked over to the bin office in a warehouse across the street. The bin office separates the orders (they print out on fan-fold paper) and sorts them into batches of 50 line item packages. These items will be given to the warehouse people the next day for order selection. At the beginning of the next day, each warehouse person receives approximately 300 line items to select. There are generally ten warehouse people selecting orders every day. The warehouse workers work four orders all at once. According to CSC personnel, it takes approximately 40-45 minutes to pick a batch of four orders. To get an idea of how the process works, imagine going grocery shopping for four people at one time. The warehouse worker basically has a grocery cart and goes up and down the aisles until each order is complete. The completed orders are placed onto a conveyor system that sends them directly to the quality control station. Quality checks are done randomly throughout the day. If an item does not pass the quality check, the order is placed on a cart for the warehouse person responsible to correct. The orders are next sent to packing where they are prepared for shipment. In addition to packing, a determination is made as to whether the order is being delivered via UPS or USPS. UPS shipments account for 95% of all deliveries, the remainder being USPS deliveries. Depending on the type of shipment (UPS or USPS) , the box is placed on one of two conveyor systems. Once the boxes are received by UPS or USPS, the CSC no longer has custody or control over the order. For this reason, the cycle time for CSC stops when the order reaches UPS and USPS shipping stations. UPS will accept shipments up until 2030 and USPS will accept shipments until 1630.

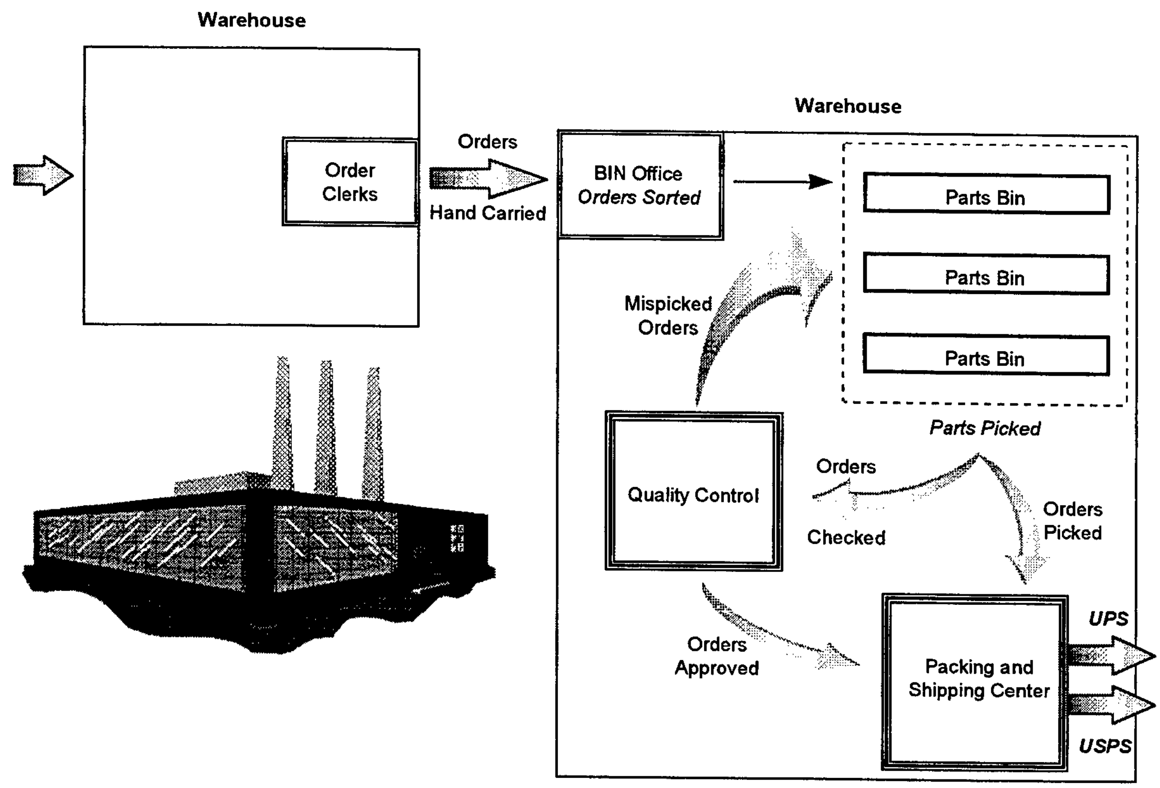


Figure 1. Current Order Fulfillment Process.

C. MODEL DEVELOPMENT

1. Overview

The models developed in this research use ARENA modeling software. ARENA is a hierarchical SIMAN/Cinema-based modeling system that can be used to model a wide variety of applications such as transportation, communications and business process reengineering. ARENA also provides an user-friendly graphical interface for building SIMAN/Cinema models.

Designing a useful simulation model that can aid the user in making decisions requires that a balance be struck between simplicity and precision. The model must behave sufficiently like the real system to allow decision makers to draw valid conclusions from its use yet minimize complexity. Highly complex models, which attempt to model every detail, are more likely to contain undetected bugs that can introduce unacceptable errors. For this reason, these simulation models tend toward minimizing complexity.

Both models in this research are designed to track a single order through the order fulfillment process. The first model reflects the order fulfillment cycle as it is currently designed, the second makes a fundamental change to the process in an attempt to reduce the cycle time of an order. Each of the simulations were run under identical conditions (i.e., original set of parameter values). The second model proposes eliminating the batch processing method that is currently being used. The input variables that drive the models will now be examined.

2. Input Variables

All simulations require input data and variables to drive the model. Time dependent data such as inter-arrival times (i.e. time between arrival of orders), delay times and processing times are one type of data that is necessary. The other type of data that is required is probabilistic data, such as the probability of an item being quality checked, the percentage of items that fail a quality check and the percentage of items shipped via UPS. Table 1 provides a summary of the input variables used in this model and the source for each data set.

Variable	Distribution/Value	Source
order inter-arrival time	exponential (1.27 min)	calculated from data
order taking process time	triangular (2,4,6 min)	GSA estimate
order picking process time	triangular (8,11,13 min)	GSA estimate
delay time to QA check	3 min	calculated from data
% of orders quality checked	7.5%	GSA estimate
process time QA check	triangular(1,3,5 min)	GSA estimate
% of order failing QA	1%	GSA data
delay time to packing	1.33 minutes	calculated from data
process time packing	uniform(3,4min)	GSA estimate
% of orders shipped UPS	95%	GSA estimate
% of orders shipped USPS	5%	GSA estimate
delay time to shipping	1.67 min	calculated from data

Table 1. Input Variables.

In the case of the inter-arrival times to the distribution center, an exponential distribution was assumed and a mean value of 1.27 minutes per order was calculated. The mean value was calculated using the total number of orders received from June 1995 to May 1996 (Appendix A). The exponential function is widely used when analyzing times between independent events such as interarrival times. Many phenomena are exponentially distributed, such as the times between arrivals of aircraft to an airport and the times between arrivals of orders to a distribution center. (Pegden, Shannon and Sadowski, 1995, p. 45)

Obtaining values for the remaining input variables is a more difficult task as there is little or no reliable data on which to calculate any values. In cases such as this, Pegden, Shannon and Sadowski (1995, p. 38) suggest that reliance on the following sources may prove to be the best option: 1) operator or designer estimates, 2) vendor claims, and 3) theoretical considerations. In the case of GSA, personnel familiar with the order fulfillment process were able to provide a "most likely estimate" and a "minimum and maximum value" for many of the input variables (Flynn, 1996). When estimates of minimum, maximum and most likely values are available the triangular distribution is the most appropriate to use (Pegden, Shannon and Sadowski, 1995, p. 41).

3. Terminating vs. Non-terminating Systems

Whether a system is terminating or non-terminating will affect the approach used to analyze simulation model results. A terminating system has a fixed starting condition (to which the system returns after each termination) and an event defining the natural end of the simulation. Post Offices and banks are examples of terminating systems because they close and empty at the end of every day and return to an idle condition ready for the beginning of the next day. A non-terminating system has neither a fixed starting condition nor a natural end point for the simulation. Hospital and distribution centers are examples of non-terminating systems. In the case of the distribution center, it does not have a fixed starting condition at the beginning of the next day. The in-process inventory is carried over from one day to the next and will vary each day.

Since there is no condition that causes the system to return to a fixed condition, there is no natural basis for selecting the starting conditions or the length of the run. This is a problem because non-terminating systems generally go through an initial transient phase that will vary with the starting conditions. After this transient phase, they have an unchanging distribution that is independent of the starting conditions. In addition, there is no definite point at which a system changes from transient to steady state. The steady state behavior of a system is what must be understood and analyzed. In modeling a non-terminating system, the transient phase introduces a bias when trying to analyze the steady state behavior of a system. The three approaches for dealing with this are:

1. reduce the transient phase by selecting the appropriate starting conditions for the run,

2. discard data during the initial portion of the simulation,

3. run the simulation long enough so that any data collected during the transient phase will be dominated by data collected during the steady state phase.

For this research one day of data during the initial phase of the simulation is discarded and the simulation is run for a moderately long period of time (30 days).

The output variables selected must be capable of measuring the desired aspects of the system. In this research, the concern is with the relationship between the cycle time of an order and in-process inventory levels. Thus, the simulation model measures the cycle time of an order from the time it arrives at the distribution center until it reaches the shipping station.

As stated above, the simulation was set for a warm-up period of one day followed by 30 replications equivalent to one day for each replication. The warm-up period allowed time for orders to be taken, sorted and batched, and for the system to reach a steady-state. The system was not reinitialized after each replication, which allowed the system to achieve a steady-state condition with requiring a warm-up period after each replication.

D. MODEL DESCRIPTION

1. "As Is" Model

The current order fulfillment process is essentially a batch processing sytem with orders printed every two hours, orders sent to a sorting and batching station where they are held until the next day, and then given to warehouse people for order fulfillment. The model reflects this batching by using *WAIT* and *SIGNAL* blocks to delay order printing by two hours and order selection by one day. The single order being tracked is worked on by a single warehouse worker. Since there are ten warehouse workers doing order selection, only 10% of the incoming orders are sent to this one warehouse worker. The remaining 90% of the orders are disposed of in the simulation model. Appendix B presents the model logic and code.

2. Reengineered Model

The reengineered model eliminates the batch process system. The business process reengineering proposal is to send orders electronically to the warehouse after the order takers have input the order into the system. The orders would be sent directly to the warehouse workers for order selection. This would essentially eliminate the one day delay under the current batch processing system. Warehouse workers could use a computer terminal to select and print the next several orders in the queue. This is the only change that has been made to this model. All other variables and parameters remain the same. Appendix C presents the model logic and code.

E. SIMULATION RESULTS

1. "As Is" Model

Table 2 presents a summary of the significant results from the simulation model. The output results for the first replication of the "As Is" model is presented in Appendix D. The output results for the first replication of the reengineered model is presented in Appendix E. The numbers in the Table below represent the averages of the 30 replications.

Indicator	"As Is" Model: average (standard error)	Reengineered Model: average (standard error)
order process time	549.89 (13.18)	49.57 (2.56)
% W/H busy	84% (.03)	81% (.02)
# of orders in pick Q	17.76 (1.61)	1.54 (.26)

Table 2. Summary of Output Results.

The average represents the sum of all the replications divided by the total number of replications. It can be seen that orders in the "As Is" model spent an average of 549.89 minutes in the system. The orders in the reengineered model spent an average of 49.57 minutes in the system. The standard error of the average order processing time for the "As Is" model is 13.18 and for the reengineered model, 2.56. The standard error represents the standard deviation of the 30 replications divided by the square root of 30. The other significant output variables presented are the percentage of time that warehouse people are busy and the number of orders in the picking queue. These have been included in the Table because the order picking station was the cause of the bottleneck within this system. The interpretations for the average, and standard error values are similar to those for observations recorded for order process time. In the case of the average, however, each value used in the calculation is weighted by the length of time for which the value persists. For example, if a variable has a value of two for one time unit and a value of six for three time units, the average over four time units is computed as (2*1 + 6*3)/4, which equals five (Pegden, Shannon and Sadowski, 1995, pp.161-162). As can be seen from the Table, the warehouse people were busy 84% of the time with a standard error of .03 and had an average of 17.76 orders in their picking queue with a standard error of 1.61. The reengineered model shows an 81% utilization rate with a standard error of .02 and had an average of 1.54 orders in the picking queue at any one time with a standard error of .26. In the next chapter a comparative analysis will be conducted along with an examination of the implications for in-process inventory levels.

IV. COMPARATIVE ANALYSIS, IMPLICATIONS AND EVALUATION

A. OVERVIEW

In this chapter the output results from the two simulation models presented in Chapter Three will be analyzed. Differences in the performance of the two systems will be examined. Additionally, the implications of the reduced cycle time will be discussed with respect to work-in-process inventory levels. A spreadsheet analysis will be conducted to demonstrate the effect that reduced cycle time will have on a distribution centers work-in-process inventory levels. The labor savings caused by the elimination of the batch processing will also be discussed and incorporated into the spreadsheet analysis.

B. COMPARATIVE ANALYSIS

Table 3 below presents the performance results of the two systems

Model	Average (Standard error)	Variation	Min.	Max.	Observation
As Is	549.89 (13.18)	.07	500.41	640.48	37.4
Reengineered	49.57 (2.56)	.29	29.64	82.94	36.0

Table 3. Order Process Time. (Based on 30 Replications)

In the "As Is" system, orders are taking, on average, over a day to process (one day is equivalent to 480 minutes). The maximum value indicates that it can take up to almost a day and a half to process an order for shipment to a customer. The design of the system makes this conclusion seem reasonable. If all incoming orders are batched and sorted for order selection the next day, then it will take at least a day to get an order processed. This batching system is a highly inefficient way to get an order out the door.

In Chapter Two, it was stated that world-class distribution centers focused on driving out processes that add no value to the order fulfillment cycle. For this distribution center, the batching and sorting process is a non-value added activity. The purpose of the order fulfillment cycle is to get the order to the customer quickly, something not done by this batching and sorting process.

The business process reengineering proposal eliminates this batching and sorting process and hence eliminates the useless one day delay. Instead of waiting every two hours to print orders they are sent electronically to the warehouse after the order is input by the order clerks. Orders are now printed out at a terminal in the warehouse as they are received. Additionally, the bin office is eliminated because two people are no longer required to sort and batch orders for the warehouse people. These people can be transferred or reassigned to other parts of the organization where they can add value to a process. The result is a reduction in cycle time from 549.89 minutes to 49.57 minutes, a 91% reduction. The implications for this reduction will be examined in the next section.

In addition to the reduction in cycle time, the other significant reduction is the number of orders in the picking queue. Table 4 presents those results.

Model	Average (Standard error)	Variation	Minimum	Maximum
As Is	17.76 (1.61)	.76	.93	39.77
Reengineered	1.54 (.26)	1.13	.10	4.93

Table 4. Number of Orders in Picking Queue.

The warehouse people are busy approximately 80% of the time versus 84% of the time in the "As Is" version. However, the number of orders in the picking queue is reduced from 17.76 orders to 1.54 orders. There is a significant degree of variation in both models. The reengineered version has a larger variation because the orders are spread out throughout the day and results in very little queuing when compared to batching.

C. IMPLICATIONS OF CYCLE TIME REDUCTION

1. Introduction

In Chapter Two it was stated that, if the amount of time it takes to process an order is reduced (cycle time), the average value of the inventory can be reduced. Since a significant cycle time reduction has been achieved through business process reengineering, what does this imply for the manager of a distribution center? Are his/her in-process inventory levels also reduced? If so, by how much and how much money can he/she afford to spend on a warehouse management system to implement this proposal? A spreadsheet is a useful tool to analyze these questions as. it can show the relationship between cycle time reduction and inventory savings.

2. Using a Spreadsheet to Analyze Inventory and Labor Savings from Reduced Cycle Times

Appendix F presents the spreadsheet used to analyze inventory and labor savings generated through various levels of cycle time reduction. Several assumptions and variables are built into the spreadsheet, thus allowing the manager a great deal of flexibility in examining his/her particular situation. The assumptions are based on estimates provided by GSA personnel and the author's experience in distribution and inventory. The assumptions and constraints which can be relaxed are:

1. Discount rate - 15%,
2. Holding cost rate - 15% of the value of the inventory,

3. Value of an inventory unit - $10,

4. Yearly Wage Cost - $30,000.

The spreadsheet incorporates the original turnaround time (approximately 9 hours) and the turnaround time reduction (approximately 7 hours) to calculate inventory savings. The elimination of the batch processing system also allowed the system to operate with two less people. Since the personnel in the bin office are no longer necessary to sort orders, at a wage cost of approximately $30,000, this amounts to a $60,000 labor savings per year. Additionally, the life cycle cost analysis allows the user to deduct any capital costs incurred with the new system and to then calculate the net savings of the cycle time reduction. It also takes into account the time value of money by using a discount rate of 15%. A vertical look-up table was constructed to allow the user to analyze net savings from various cycle time reductions and analyze various proposals. Generally, higher level cycle time reductions will cost more money. Any of the above constraints can be relaxed to reflect a particular situation the manager is facing.

In the case of the GSA distribution center, the simulation model indicates that the cycle time of an order can be reduced by approximately 7.2 hours. Using the spreadsheet in Appendix F, savings are as follows:

Cycle Time Reduction	7 hours
Labor Savings	$60,000/yr
Inventory Reduction	1946 units
Value of Inventory Reduction ($10/unit)	$19,460
Inventory Savings (15% holding cost)	$2,919/year
Net Present Value of Cumulative Savings (15% discount rate, 5 years)	$234,669

Table 5. Estimated Savings from Reengineering Proposal

3. Using a Spreadsheet to Conduct Payback Analysis

The manager of the distribution center will also be interested in determining how long it will take to earn back the investment required to implement the business process reengineering proposal. Appendix G's two spreadsheets graphically present the results of the payback analysis. One shows the payback period using undiscounted savings and costs. The other shows the payback period using discounted savings and costs, and uses a discount rate of 15% to account for the time value of money. Both methods (undiscounted and discounted) show a payback beginning immediately.

D. EVALUATION OF THE MODELS BASED ON THE SIMULATION RESULTS AND SPREADSHEET ANALYSIS

This author concludes that the GSA distribution center in Stockton, CA. is most certainly operating inefficiently. The simulation model has shown that cycle times can be reduced by 90% by eliminating the current batch processing system. It has been shown that by reducing cycle times, in-process inventory levels can be reduced by 77%, and that, a labor savings of $60,000 per year can be generated. With an initial capital investment of $5,000, total savings of approximately $234,669 are feasible over five year time frame. The large majority of the savings come from labor cost reductions due to the reegineered order fulfillment process. While these personnel will not be terminated, they certainly can be reasigned or transferred to another part of the organization. As personnel retire or leave the organization, GSA can choose not to replace them. This would allow GSA to obtain the labor cost savings in the form of attrition. These savings may not seem significant in light of the size of the GSA organization. However, if it is realized that the CSC is one small part of GSA's Western Distribution Center and that if these concepts and techniques are applied to the entire organization, it can be concluded that the savings from similar projects will be significant to the organization. These concepts and techniques are certainly applicable throughout the organization and therefore, can lead to significant reductions in cycle time and inventory levels. The next Chapter will present a summary of the thesis research, conclusions, including implications for the DoD, and some recommendations for additional improvements.

V. SUMMARY, RECOMMENDATIONS FOR FURTHER STUDY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The objective in the thesis was to examine how the DoD can reduce inventory levels by reducing cycle times in its distribution centers. Business process reengineering and simulation modeling were the two tools used to analyze these concepts. The order fulfillment process at GSA's Distribution Center in Stockton, CA. was the site analyzed. It was modeled using the ARENA software simulation package. One year's worth of demand history was used to create incoming orders for the model which focused on achieving cycle time reduction in order to achieve reductions in inventory levels.

Chapter II provided background material on warehousing and distribution, inventory in a distribution center, the relationship between cycle time and inventory, reengineering, DoD inventory and simulation modeling. Chapter III presented an overview of GSA and what it does, discussed the GSA order fulfillment process, described the simulation model developed and presented the results of the two simulation models developed for the distribution center. Chapter IV presented a comparative analysis of the two models along with the implications of those results. Additionally, a spreadsheet analysis was conducted to determine how much money could be saved by implementing the proposed reengineered model.

B. RECOMMENDATIONS FOR FURTHER STUDY

This field of study is replete with additional areas for study and research. This author has two major recommendations regarding this field of study.

1. Refine the Simulation

The simulation model developed in this thesis can certainly be improved upon. These refinements can be used to analyze the effects of the number of warehouse workers on cycle time. If the system is reengineered, are the same number of workers needed to get product out the door? This would involve analyzing the utilization rates of the warehouse workers. The model can also be designed to measure the number of unprocessed orders at the end of the day. This will give the distribution center manager the ability to see when his order fulfillment process is backing up. The model can also be designed to measure the amount of time an order spends in any particualar queue. This gives the distribution center manager the ability to see where the bottlenecks are ocurring. Further output analysis can tell the distribution center manager the probability of getting an order out the door in a defined amount of time.

2. DoD Distribution Centers and the Measurement of Cycle Time

If the DoD is to use cycle time reduction to reduce its inventory levels, then it must recognize the importance of measuring how long it takes an order to move from order entry through shipment. Very little work is being in the DoD regarding the measurement of cycle time in a distribution center. If cycle time is going to be reduced, it must begin to be measured and measured correctly.

C. CONCLUSIONS AND RECOMMENDATIONS

1. Inventory Reduction and Cycle Time

Cycle time reduction offers a significant means to reduce in-process inventories. The application of Little's Law and cycle time reduction to the processes in a distribution center can be used by the distribution center manager to reduced his/her inventory levels and save scarce resources. The model indicated cycle time reductions of 91%, lowered inventory levels of 77% and a labor cost savings of $60,000 per year. Additionally, by shortening the logistics response time, product is flowing through the distribution center faster and getting to the ultimate consumer far more quickly. Since the GSA Western Distribution Center is a typical example of a DoD distribution center, it follows that the idea of cycle time reduction can be used by any distribution center to reduce its inventory levels.

2. Use of Simulation Modeling

Simulation modeling offers a powerful and cost effective method to reengineer a business process. It allow analysts, managers, and users to examine and consider various reengineering proposals without a great deal of investment in time and money. "What if" analysis under various constraints can be conducted until the management of the organization is satisfied with the proposed changes.

It is critical to understand that simulation modeling will not provide an optimal solution to the issue being examined. However, it is an extremely powerful decision aid if used properly. The effectiveness of the model depends on the validity of the data, its assumptions and the internal logic of the model. Because of this, the output data must be scrutinized carefully to ensure the results are as expected for the scenarios being analyzed.

These cautions should not dissuade the analyst from using simulation modeling as a legitimate decision making tool.

3. Labor Savings

The majority of the savings from this BPR proposal come in the form of labor savings. The elimination of the bin office frees up two people that can be used elsewhere in the organization. This causes a labor savings of $60,000 per year for the CSC organization. These two people can certainly be used in another part of the organization where they can add value to a process that can actually use their skills. Additionally, even if they cannot be used elsewhere in the organization immediately, GSA can use attrition to obtain their labor savings. As people in the organization leave or retire they will not be replaced by new hires.

4. Implications for the Department of Defense

By focusing on cycle time reduction, the DoD can not only get products to the customer more quickly, but it can also reduce its investment in inventory. As was stated earlier, these two objectives, reducing logistics response time and reducing inventory investment, are two of DoD's primary logistics goals. Additionally, in the course of business process reengineering labor efficiencies are often realized in the form of streamlined business procedures. The use of business process reengineering offers the DoD a valid methodology to examine, redefine and reengineer current business processes.

5. Recommmedations

a. GSA

1. Procure the necessary hardware and software to implement new warehouse system.

2. Upon implementation of new warehouse system, transfer bin office personnel to another part of the GSA Western Distribution Center.

3. Begin the search for additional opportunities to reduce cycle time using simulation modeling.

b. DoD

1. Begin a pilot project within DoD to measure and analyze the cycle time of products flowing through DoD distribution centers.

2. Use a commercial off-the-shelf simulation software package to graphically demonstrate orders flowing through a distribution center. Use simulation modeling as a decision aid in the reengineering of distribution center processes.

3. Train distribution center mangers to use the concept of cycle time reduction as a valid means to reduce inventory levels.

The importance of these recommendations to DoD cannot be underestimated. The DoD will contine to see additional resource constraints as it stuggles to meet increasing world comittments with ever-decreasing budget dollars. Under continuing pressure from taxpayers, the United States Congress and the GAO to find better ways to conduct business, DoD must find ways to do more with less. The implementation of the recommendations will be a solid first step in meeting these demands.

APPENDIX A: DAILY ORDER SPREADSHEET

Daily Orders Received at the Customer Support Center												
June 1995 thru May 1996												
Day-Week	May-96	Apr-96	Mar-96	Feb-96	Jan-96	Dec-95	Nov-95	Oct-95	Sep-95	Aug-95	Jul-95	Jun-95
Mon-1		326						212			188	
Tues-1		376			219			232		423		
Wed-1	410	494			345		384	293		467	323	
Thur-1	293	418		418	346		365	315		398	360	400
Fri-1	431	372	341	425	324	383	311	279	432	409	359	458
Mon-2	389	368	102	370	307	460	371			356	357	364
Tues-2	396	399	401	451	579	440	402	279	333	423	415	470
Wed-2	415	376	488	466	490	396	404	330	383	422	446	407
Thur-2	368	406	552	414	482	438	352	281	413	422	438	395
Fri-2	366	418	466	385	405	394		300	332	410	440	429
Mon-3	327	291	331	401		346	357	306	442	359	376	356
Tues-3	462	453	291	424	379	355	244	352	491	413	459	450
Wed-3	425	450	524	364	443	415	183	345	462	425	426	353
Thur-3	413	460	394	461	495	410	263	379	484	416	395	467
Fri-3	416	412	407	354	478	338	200	297	463	428	259	410
Mon-4		362	414		451	295	283	302	340	377	504	326
Tues-4	242	404	478	293	441	300	349	361	376	463	478	426
Wed-4	346	445	462	453	571	324	345	355	406	423	470	433
Thur-4	314	416	415	409	469	298		383	404	444	497	454
Fri-4	454	447	415	389	481	174	122	352	423	402	363	409
Mon-5		334	274	335	315		310	296	320	396	385	310
Tues-5		436	472	419	431	166	393	336	394	422		381
Wed-5			400	434	402	237	358		361	429		370
Thur-5			404	385		235	408		449	375		387
Fri-5			433			201			434			365
Totals	6467	8863	8464	8050	8853	6605	6404	6585	8142	9502	7938	8820
Daily Aver.	380.4	402.9	403.0	402.5	421.6	330.3	320.2	313.6	407.1	413.1	396.9	400.9
St. Dev.	59.7	48.9	98.0	44.3	89.6	90.4	80.7	44.5	51.7	27.9	63.6	45.1
Av/Hr	47.6	50.4	50.4	50.3	52.7	41.3	40.0	39.2	50.9	51.6	49.6	50.1
Inter-Arr	1.26	1.19	1.19	1.19	1.14	1.45	1.50	1.53	1.18	1.16	1.21	1.20
Grand Totals:												
Nbr of Orders		94,693										
Orders/Day		382.7										
Orders/Hr		47.8										
Min/Order		1.27										

APPENDIX B: "AS IS" SCENARIO (ARENA PROGRAM)

```
;
;
;     Model statements for module:  Create 2
;

20$           CREATE,         1,0:120;
27$           TRACE,          -1,"-Entity Created\n";
24$           ASSIGN:         Picture=Default:NEXT(0$);


;
;
;     Model statements for module:  Signal 1
;
0$            TRACE,          -1,"-Sending signal 8\n";
28$           SIGNAL:         8:NEXT(1$);


;
;
;     Model statements for module:  Dispose 1
;
1$            TRACE,          -1,"-Disposing entity\n";
29$           DISPOSE;


;
;
;     Model statements for module:  Create 1
;

30$           CREATE,         1:EXPO(1.27):MARK(Time In);
37$           TRACE,          -1,"-Entity Created\n";
34$           ASSIGN:         Picture=Default:NEXT(18$);


;
;
;     Model statements for module:  Server 2
;

18$           STATION,        OrderTakers;
115$          TRACE,          -1,"-Arrived to station OrderTakers\n";
78$           DELAY:          0.;
122$          TRACE,          -1,"-Waiting for resource OrderTakers_R\n";
38$           QUEUE,          OrderTakers_R_Q:MARK(QueueTime);
39$           SEIZE,          1:OrderTakers_R,1;
52$           TALLY:          OrderTakers_R_Q Queue Time,INT(QueueTime),1;
              TRACE,          -1,"-Delay for processing time TRIA( 2, 4 , 6)\n";
40$           DELAY:          TRIA( 2, 4 , 6);
123$          TRACE,          -1,"-Releasing resource\n";
41$           RELEASE:        OrderTakers_R,1;
106$          DELAY:          0.;
129$          TRACE,          -1,"-Transferred to next module\n"::NEXT(Print Buffer);


;
;
;     Model statements for module:  Wait 1
;
Print Buffer  TRACE,          -1,"-Waiting for signal 8\n";
149$          WAIT:           8;
151$          DELAY:          0.000:NEXT(SplitBatch);


;
```

```
;
;     Model statements for module:  Inspect 3
;

SplitBatch      STATION,        SplitBatch;
265$            TRACE,          -1,"-Arrived to Inspect station SplitBatch\n";
206$            DELAY:          0.;
152$            QUEUE,          SplitBatch_R_Q:MARK(QueueTime);
153$            SEIZE,          1:SplitBatch_R,1;
167$            TALLY:          SplitBatch_R_Q Queue Time,INT(QueueTime),1;
                TRACE,          -1,"-Delay for processing time 0. with failure probability
.90\n";
154$            DELAY:          0.;
162$            BRANCH,         1:With,.90,273$,Yes:
                                Else,272$,Yes;
273$            TRACE,          -1,"-Entity failed inspection\n";
258$            DELAY:          0.0;
217$            RELEASE:        SplitBatch_R,1;
242$            DELAY:          0.;
278$            TRACE,          -1,"-Transferred to next module\n"::NEXT(9$);

272$            TRACE,          -1,"-Entity passed inspection\n";
257$            DELAY:          0.0;
155$            RELEASE:        SplitBatch_R,1;
241$            DELAY:          0.;
284$            TRACE,          -1,"-Transferred to next module\n"::NEXT(10$);


;
;
;     Model statements for module:  Station 4
;

10$             STATION,        WaitADay;
319$            TRACE,          -1,"-Arrived to station
WaitADay\n"::NEXT(ReleaseMasterBatch);


;
;
;     Model statements for module:  Wait 2
;
ReleaseMasterBatch TRACE,       -1,"-Waiting for signal 10\n";
321$            WAIT:           10;
323$            DELAY:          0.000:NEXT(14$);


;
;
;     Model statements for module:  Assign 4
;
14$             TRACE,          -1,"-Making assignments\n";
324$            ASSIGN:         Orders2Pick=Orders2Pick+1:NEXT(11$);


;
;
;     Model statements for module:  Count 2
;
11$             TRACE,          -1,"-Updating counter OrdersIn \n";
325$            COUNT:          OrdersIn,1:NEXT(Order Selection);


;
;
;     Model statements for module:  Server 1
;

Order Selection STATION,        Picking;
404$            TRACE,          -1,"-Arrived to station Picking\n";
367$            DELAY:          0.;
411$            TRACE,          -1,"-Waiting for resource Picking_R\n";
327$            QUEUE,          Picking_R_Q:MARK(QueueTime);
328$            SEIZE,          1:Picking_R,1;
341$            TALLY:          Picking_R_Q Queue Time,INT(QueueTime),1;
```

```
                TRACE,          -1,"-Delay for processing time TRIA( 8 , 11, 13)\n";
329$            DELAY:          TRIA( 8 , 11, 13);
412$            TRACE,          -1,"-Releasing resource\n";
330$            RELEASE:        Picking_R,1;
413$            TRACE,          -1,"-Delay for loading time 3\n";
395$            DELAY:          3;
417$            TRACE,          -1,"-Transferred to station Quality\n";
335$            ROUTE:          3.,Quality;


;
;
;      Model statements for module:  Station 3
;

9$              STATION,        ExtraOrders;
439$            TRACE,          -1,"-Arrived to station ExtraOrders\n"::NEXT(UnusedBatches);


;
;
;      Model statements for module:  Dispose 5
;
UnusedBatches TRACE,            -1,"-Disposing entity\n";
441$            DISPOSE;


;
;
;      Model statements for module:  Station 2
;

USPS Ship       STATION,        USPS;
443$            TRACE,          -1,"-Arrived to station USPS\n"::NEXT(12$);


;
;
;      Model statements for module:  Assign 3
;
12$             TRACE,          -1,"-Making assignments\n";
445$            ASSIGN:         Norders=Norders+1:NEXT(13$);


;
;
;      Model statements for module:  Count 4
;
13$             TRACE,          -1,"-Updating counter ByeBye \n";
446$            COUNT:          ByeBye,1:NEXT(17$);


;
;
;      Model statements for module:  Depart 4
;

17$             STATION,        Depart 4;
478$            TRACE,          -1,"-Arrived to station Depart 4\n";
448$            DELAY:          0.;
470$            COUNT:          Depart 4_C,1;
475$            TALLY:          Depart 4_Ta,Interval(Time In),1;
485$            TRACE,          -1,"-Disposing entity\n";
477$            DISPOSE;


;
;
;      Model statements for module:  Station 1
;

UPS Ship        STATION,        UPS;
488$            TRACE,          -1,"-Arrived to station UPS\n"::NEXT(12$);
```

```
;
;
;     Model statements for module:  Create 3
;

490$          CREATE,        1,960:480;
497$          TRACE,         -1,"-Entity Created\n";
494$          ASSIGN:        Picture=Default:NEXT(15$);


;
;
;     Model statements for module:  Assign 5
;
15$           TRACE,         -1,"-Making assignments\n";
498$          ASSIGN:        UnprocessedOrders=Orders2Pick-Norders:NEXT(5$);


;
;
;     Model statements for module:  Tally 1
;
5$            TRACE,         -1,"-Updating Tally N of unprocessed orders \n";
499$          TALLY:         N of unprocessed orders,Orders2Pick-Norders,1:NEXT(16$);


;
;
;     Model statements for module:  Dispose 7
;
16$           TRACE,         -1,"-Disposing entity\n";
501$          DISPOSE;


;
;
;     Model statements for module:  Chance 2
;
QC            TRACE,         -1,"-Choosing from 2 options\n";
502$          BRANCH,        1:With,.075,Inspection,Yes:
                             Else,Pack,Yes;

;
;
;     Model statements for module:  Inspect 2
;

Inspection    STATION,       Quality;
616$          TRACE,         -1,"-Arrived to Inspect station Quality\n";
557$          DELAY:         0.;
503$          QUEUE,         Quality_R_Q;
504$          SEIZE,         1:Quality_R,1;
              TRACE,         -1,"-Delay for processing time TRIA(1,3,5) with failure
probability .01\n";
505$          DELAY:         TRIA(1,3,5);
513$          BRANCH,        1:With,.01,624$,Yes:
                             Else,623$,Yes;
624$          TRACE,         -1,"-Entity failed inspection\n";
609$          DELAY:         0.0;
568$          RELEASE:       Quality_R,1;
593$          DELAY:         0.;
628$          TRACE,         -1,"-Transferred to station Picking\n";
512$          ROUTE:         5.,Picking;

623$          TRACE,         -1,"-Entity passed inspection\n";
608$          DELAY:         0.0;
506$          RELEASE:       Quality_R,1;
592$          DELAY:         0.;
634$          TRACE,         -1,"-Transferring to station Packing\n";
511$          ROUTE:         1.33,Packing;


;
;
;     Model statements for module:  Inspect 1
```

```
;

Pack            STATION,        Packing;
782$            TRACE,          -1,"-Arrived to Inspect station Packing\n";
723$            DELAY:          0.;
669$            QUEUE,          Packing_R_Q;
670$            SEIZE,          1:Packing_R,1;
                TRACE,          -1,"-Delay for processing time UNIF( 3,4) with failure
probability .05\n";
671$            DELAY:          UNIF( 3,4);
679$            BRANCH,         1:With,.05,790$,Yes:
                                Else,789$,Yes;
790$            TRACE,          -1,"-Entity failed inspection\n";
775$            DELAY:          0.0;
734$            RELEASE:        Packing_R,1;
759$            DELAY:          0.;
794$            TRACE,          -1,"-Transferred to station USPS\n";
678$            ROUTE:          2,USPS;

789$            TRACE,          -1,"-Entity passed inspection\n";
774$            DELAY:          0.0;
672$            RELEASE:        Packing_R,1;
758$            DELAY:          0.;
800$            TRACE,          -1,"-Transferring to station UPS\n";
677$            ROUTE:          1.67,UPS;


;
;
;      Model statements for module:  Create 5
;

835$            CREATE,         1,0:480;
842$            TRACE,          -1,"-Entity Created\n";
839$            ASSIGN:         Picture=Default:NEXT(6$);


;
;
;      Model statements for module:  Signal 3
;
6$              TRACE,          -1,"-Sending signal 10\n";
843$            SIGNAL:         10:NEXT(7$);


;
;
;      Model statements for module:  Dispose 4
;
7$              TRACE,          -1,"-Disposing entity\n";
844$            DISPOSE;
```

APPENDIX C: REEGINEERED SCENARIO (ARENA PROGRAM)

```
;
;
;     Model statements for module:  Create 1
;

15$           CREATE,         1:EXPO(1.27):MARK(Time In);
22$           TRACE,          -1,"-Entity Created\n";
19$           ASSIGN:         Picture=Default:NEXT(13$);


;
;
;     Model statements for module:  Server 2
;

13$           STATION,        OrderTakers;
100$          TRACE,          -1,"-Arrived to station OrderTakers\n";
63$           DELAY:          0.;
107$          TRACE,          -1,"-Waiting for resource OrderTakers_R\n";
23$           QUEUE,          OrderTakers_R_Q:MARK(QueueTime);
24$           SEIZE,          1:OrderTakers_R,1;
37$           TALLY:          OrderTakers_R_Q Queue Time,INT(QueueTime),1;
              TRACE,          -1,"-Delay for processing time TRIA( 2, 4 , 6)\n";
25$           DELAY:          TRIA( 2, 4 , 6);
108$          TRACE,          -1,"-Releasing resource\n";
26$           RELEASE:        OrderTakers_R,1;
91$           DELAY:          0.;
114$          TRACE,          -1,"-Transferred to next module\n"::NEXT(SplitBatch);


;
;
;     Model statements for module:  Inspect 3
;

SplitBatch    STATION,        SplitBatch;
247$          TRACE,          -1,"-Arrived to Inspect station SplitBatch\n";
188$          DELAY:          0.;
134$          QUEUE,          SplitBatch_R_Q:MARK(QueueTime);
135$          SEIZE,          1:SplitBatch_R,1;
149$          TALLY:          SplitBatch_R_Q Queue Time,INT(QueueTime),1;
              TRACE,          -1,"-Delay for processing time 0. with failure probability
.90\n";
136$          DELAY:          0.;
144$          BRANCH,         1:With,.90,255$,Yes:
                              Else,254$,Yes;
255$          TRACE,          -1,"-Entity failed inspection\n";
240$          DELAY:          0.0;
199$          RELEASE:        SplitBatch_R,1;
224$          DELAY:          0.;
260$          TRACE,          -1,"-Transferred to next module\n"::NEXT(5$);

254$          TRACE,          -1,"-Entity passed inspection\n";
239$          DELAY:          0.0;
137$          RELEASE:        SplitBatch_R,1;
223$          DELAY:          0.;
266$          TRACE,          -1,"-Transferred to next module\n"::NEXT(9$);


;
;
;     Model statements for module:  Assign 4
;
9$            TRACE,          -1,"-Making assignments\n";
300$          ASSIGN:         Orders2Pick=Orders2Pick+1:NEXT(6$);
```

```
;
;
;     Model statements for module:  Count 2
;
6$            TRACE,         -1,"-Updating counter OrdersIn \n";
301$          COUNT:         OrdersIn,1:NEXT(Order Selection);


;
;
;     Model statements for module:  Server 1
;

Order Selection STATION,     Picking;
380$          TRACE,         -1,"-Arrived to station Picking\n";
343$          DELAY:         0.;
387$          TRACE,         -1,"-Waiting for resource Picking_R\n";
303$          QUEUE,         Picking_R_Q:MARK(QueueTime);
304$          SEIZE,         1:Picking_R,1;
317$          TALLY:         Picking_R_Q Queue Time,INT(QueueTime),1;
              TRACE,         -1,"-Delay for processing time TRIA( 8 , 11, 13)\n";
305$          DELAY:         TRIA( 8 , 11, 13);
388$          TRACE,         -1,"-Releasing resource\n";
306$          RELEASE:       Picking_R,1;
389$          TRACE,         -1,"-Delay for loading time 3\n";
371$          DELAY:         3;
393$          TRACE,         -1,"-Transferred to station Quality\n";
311$          ROUTE:         3.,Quality;


;
;
;     Model statements for module:  Station 3
;

5$            STATION,       ExtraOrders;
415$          TRACE,         -1,"-Arrived to station ExtraOrders\n"::NEXT(UnusedBatches);


;
;
;     Model statements for module:  Dispose 5
;
UnusedBatches TRACE,         -1,"-Disposing entity\n";
417$          DISPOSE;


;
;
;     Model statements for module:  Station 2
;

USPS Ship     STATION,       USPS;
419$          TRACE,         -1,"-Arrived to station USPS\n"::NEXT(7$);


;
;
;     Model statements for module:  Assign 3
;
7$            TRACE,         -1,"-Making assignments\n";
421$          ASSIGN:        Norders=Norders+1:NEXT(8$);


;
;
;     Model statements for module:  Count 4
;
8$            TRACE,         -1,"-Updating counter ByeBye \n";
422$          COUNT:         ByeBye,1:NEXT(12$);


;
;
```

```
;     Model statements for module:  Depart 4
;

12$           STATION,       Depart 4;
454$          TRACE,         -1,"-Arrived to station Depart 4\n";
424$          DELAY:         0.;
446$          COUNT:         Depart 4_C,1;
451$          TALLY:         Depart 4_Ta,Interval(Time In),1;
461$          TRACE,         -1,"-Disposing entity\n";
453$          DISPOSE;


;
;
;     Model statements for module:  Station 1
;

UPS Ship      STATION,       UPS;
464$          TRACE,         -1,"-Arrived to station UPS\n"::NEXT(7$);


;
;
;     Model statements for module:  Create 3
;

466$          CREATE,        1,960:480;
473$          TRACE,         -1,"-Entity Created\n";
470$          ASSIGN:        Picture=Default:NEXT(10$);


;
;
;     Model statements for module:  Assign 5
;
10$           TRACE,         -1,"-Making assignments\n";
474$          ASSIGN:        UnprocessedOrders=Orders2Pick-Norders:NEXT(3$);


;
;
;     Model statements for module:  Tally 1
;
3$            TRACE,         -1,"-Updating Tally N of unprocessed orders \n";
475$          TALLY:         N of unprocessed orders,Orders2Pick-Norders,1:NEXT(11$);


;
;
;     Model statements for module:  Dispose 7
;
11$           TRACE,         -1,"-Disposing entity\n";
477$          DISPOSE;


;
;
;     Model statements for module:  Chance 2
;
QC            TRACE,         -1,"-Choosing from 2 options\n";
478$          BRANCH,        1:With,.075,Inspection,Yes:
                             Else,Pack,Yes;

;
;
;     Model statements for module:  Inspect 2
;

Inspection    STATION,       Quality;
592$          TRACE,         -1,"-Arrived to Inspect station Quality\n";
533$          DELAY:         0.;
479$          QUEUE,         Quality_R_Q;
480$          SEIZE,         1:Quality_R,1;
              TRACE,         -1,"-Delay for processing time TRIA(1,3,5) with failure
probability .01\n";
```

```
481$            DELAY:          TRIA(1,3,5);
489$            BRANCH,         1:With,.01,600$,Yes:
                                Else,599$,Yes;
600$            TRACE,          -1,"-Entity failed inspection\n";
585$            DELAY:          0.0;
544$            RELEASE:        Quality_R,1;
569$            DELAY:          0.;
604$            TRACE,          -1,"-Transferred to station Picking\n";
488$            ROUTE:          5.,Picking;

599$            TRACE,          -1,"-Entity passed inspection\n";
584$            DELAY:          0.0;
482$            RELEASE:        Quality_R,1;
568$            DELAY:          0.;
610$            TRACE,          -1,"-Transferring to station Packing\n";
487$            ROUTE:          1.33,Packing;


;
;
;    Model statements for module:  Inspect 1
;

Pack            STATION,        Packing;
758$            TRACE,          -1,"-Arrived to Inspect station Packing\n";
699$            DELAY:          0.;
645$            QUEUE,          Packing_R_Q;
646$            SEIZE,          1:Packing_R,1;
                TRACE,          -1,"-Delay for processing time UNIF( 3,4) with failure
probability .05\n";
647$            DELAY:          UNIF( 3,4);
655$            BRANCH,         1:With,.05,766$,Yes:
                                Else,765$,Yes;
766$            TRACE,          -1,"-Entity failed inspection\n";
751$            DELAY:          0.0;
710$            RELEASE:        Packing_R,1;
735$            DELAY:          0.;
770$            TRACE,          -1,"-Transferred to station USPS\n";
654$            ROUTE:          2,USPS;

765$            TRACE,          -1,"-Entity passed inspection\n";
750$            DELAY:          0.0;
648$            RELEASE:        Packing_R,1;
734$            DELAY:          0.;
776$            TRACE,          -1,"-Transferring to station UPS\n";
653$            ROUTE:          1.67,UPS;
```

APPENDIX D: SAMPLE OUTPUT OF "AS IS" REPLICATIONS

ARENA Simulation Results
NPS - License # 90106

Summary for Replication 1 of 30

Project: GSA Distribution Ctr
Analyst: J.F.Bennett

Run execution date : 12/ 7/1996
Model revision date: 6/ 7/1996

Replication ended at time : 960.0
Statistics were cleared at time: 480.0
Statistics accumulated for time: 480.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Time in system	--	--	--	--	0
Picking_R_Q Queue Time	190.20	.61599	.00000	387.33	39
OrderTakers_R_Q Queue	.04589	5.7938	.00000	2.3432	354
SplitBatch_R_Q Queue T	.00000	--	.00000	.00000	459
N of unprocessed order	.00000	--	.00000	.00000	1
Depart 4_Ta	482.10	.10242	416.51	744.22	37

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
# in OrderTakers_R_Q	.03384	9.1989	.00000	5.0000	.00000
Picking_R Busy	.85347	.41435	.00000	1.0000	1.0000
SplitBatch_R Available	1.0000	.00000	1.0000	1.0000	1.0000
OrderTakers_R Busy	2.9414	.57491	.00000	7.0000	6.0000
Quality_R Available	1.0000	.00000	1.0000	1.0000	1.0000
# in Packing_R_Q	.00000	--	.00000	.00000	.00000
SplitBatch_R Busy	.00000	--	.00000	1.0000	.00000
Packing_R Available	1.0000	.00000	1.0000	1.0000	1.0000
# in Quality_R_Q	.00000	--	.00000	.00000	.00000
OrderTakers_R Availabl	7.0000	.00000	7.0000	7.0000	7.0000
Quality_R Busy	.25152	1.7250	.00000	1.0000	.00000
# in SplitBatch_R_Q	.00000	--	.00000	.00000	.00000
# in Picking_R_Q	15.454	.75922	.00000	36.000	27.000
Packing_R Busy	.27305	1.6316	.00000	1.0000	.00000
Picking_R Available	1.0000	.00000	1.0000	1.0000	1.0000

COUNTERS

Identifier	Count	Limit
OrdersIn	65	Infinite
ByeBye	37	Infinite
Depart 4_C	37	Infinite

Execution time: 0.55 minutes.
Simulation run complete.

APPENDIX E: SAMPLE OUTPUT OF REENGINEERED REPLICATIONS

ARENA Simulation Results
NPS - License # 90106

Summary for Replication 1 of 30

Project: GSA Distribution Ctr
Analyst: J.F.Bennett

Run execution date : 12/ 7/1996
Model revision date: 6/ 7/1996

Replication ended at time : 960.0
Statistics were cleared at time: 480.0
Statistics accumulated for time: 480.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Time in system	--	--	--	--	0
Picking_R_Q Queue Time	11.794	1.1408	.00000	45.042	31
OrderTakers_R_Q Queue	.02935	6.8300	.00000	2.6523	363
SplitBatch_R_Q Queue T	.00000	--	.00000	.00000	361
N of unprocessed order	3.0000	.00000	3.0000	3.0000	1
Depart 4_Ta	42.036	.32481	25.425	74.678	29

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
# in OrderTakers_R_Q	.02219	9.2186	.00000	3.0000	.00000
Picking_R Busy	.66048	.71697	.00000	1.0000	1.0000
SplitBatch_R Available	1.0000	.00000	1.0000	1.0000	1.0000
OrderTakers_R Busy	2.9320	.61098	.00000	7.0000	6.0000
Quality_R Available	1.0000	.00000	1.0000	1.0000	1.0000
# in Packing_R_Q	.00000	--	.00000	.00000	.00000
SplitBatch_R Busy	.00000	--	.00000	1.0000	.00000
Packing_R Available	1.0000	.00000	1.0000	1.0000	1.0000
# in Quality_R_Q	.00000	--	.00000	.00000	.00000
OrderTakers_R Availabl	7.0000	.00000	7.0000	7.0000	7.0000
Quality_R Busy	.17556	2.1670	.00000	1.0000	.00000
# in SplitBatch_R_Q	.00000	--	.00000	.00000	.00000
# in Picking_R_Q	.76636	1.5490	.00000	5.0000	1.0000
Packing_R Busy	.20942	1.9429	.00000	1.0000	.00000
Picking_R Available	1.0000	.00000	1.0000	1.0000	1.0000

COUNTERS

Identifier	Count	Limit
OrdersIn	32	Infinite
ByeBye	29	Infinite
Depart 4_C	29	Infinite

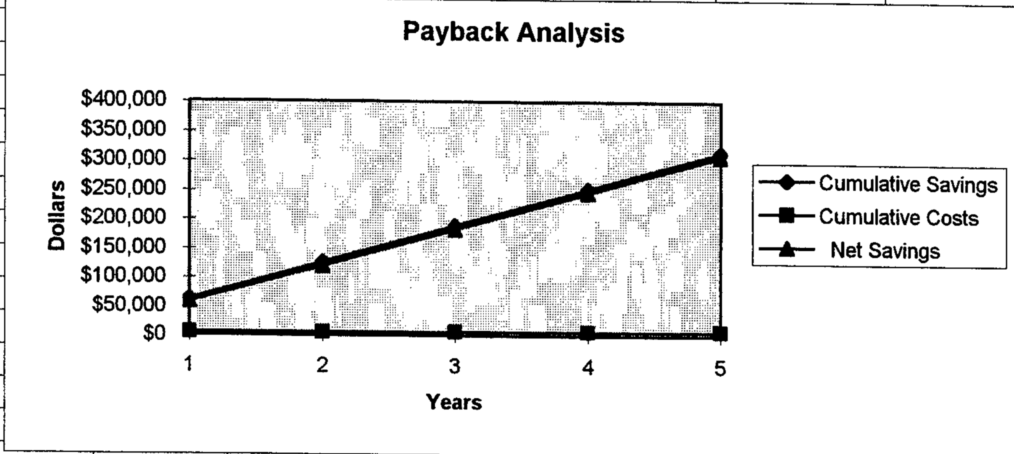
Execution time: 0.57 minutes.
Simulation run complete.

APPENDIX F: LOGISTIC SUPPORT ANALYSIS

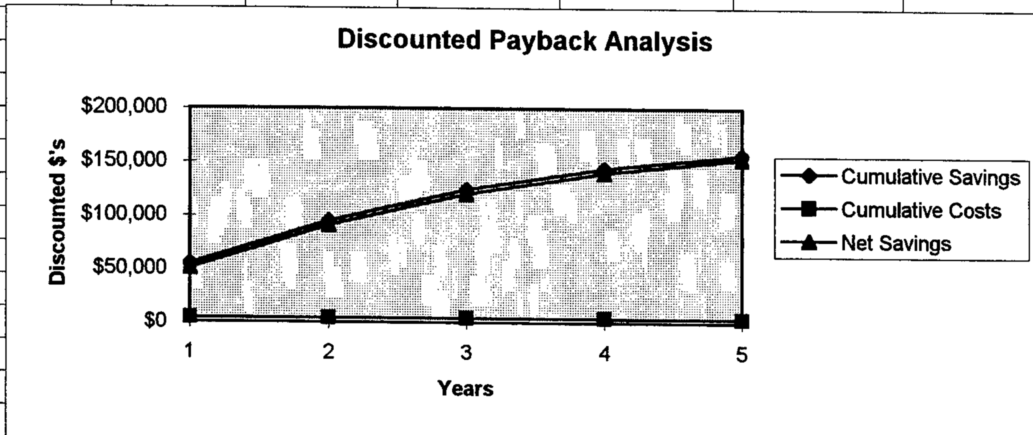
Logistic Support Analysis				Discount Rate			Cost Data		
Government Services Administration				15%					
Customer Support Center							Holding Costs		15%
Order Fulfillment Process							Value/Inventory Unit		$10
Process Data									
Original Turnaround Time (hrs)			9						
Turnaround Time Reduction(hrs)			7			**Inventory Cost Data**			
Production Rate(units/hr)			278			Value of Orig Inv		$25,020	
						Value of Inv Red		$19,460	
						Val of Red Inv		$5,560	
Original Work-In-Process			2502			Inv Savings		$2,919	
Work-in-Process Reduction			1946						
New Work-in-Process			556						
		LIFE CYCLE COST ANALYSIS							
	Year	1	2	3	4	5			
Inventory Savings		$2,919	$2,919	$2,919	$2,919	$2,919			
Labor Savings		$60,000	$60,000	$60,000	$60,000	$60,000			
Capital Cost		$5,000	$600	$600	$600	$600			
Net Savings		$57,919	$62,319	$62,319	$62,319	$62,319			
Discounted Value		$44,619	$47,512	$47,512	$47,512	$47,512			
Cumulative Dis Value		$44,619	$92,132	$139,644	$187,156	$234,669			
Look-up Table: Capital Cost(w-i-p reduction in hours)									
t.a.t. red	1	2	3	4	5				
0	$0	$0	$0	$0	$0				
2	$1,000	$200	$200	$200	$200				
4	$3,000	$300	$300	$300	$300				
7	$5,000	$600	$600	$600	$600				

APPENDIX G: PAYBACK ANALYSIS

	Payback Analysis				
Year	1	2	3	4	5
Cumulative Savings	$62,919	$125,838	$188,757	$251,676	$314,595
Cumulative Costs	$5,000	$5,600	$6,200	$6,800	$7,400
Net Savings	$57,919	$120,238	$182,557	$244,876	$307,195



	Disounted Payback Analysis				
Year	1	2	3	4	5
Cumulative Savings	$54,712	$95,152	$124,111	$143,897	$156,409
Cumulative Costs	$4,348	$4,234	$4,077	$3,888	$3,679
Net Savings	$50,364	$90,917	$120,034	$140,009	$152,730



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